PB88-104153

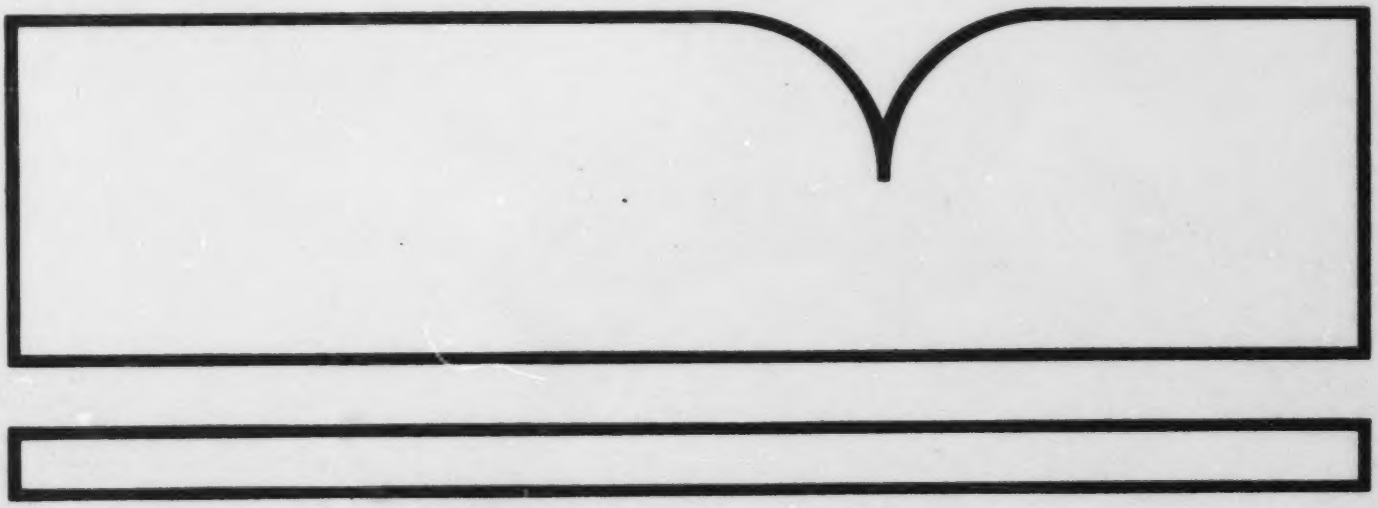
Screening Methods for the Identification of Organic Emissions from Indoor Air Pollution Sources

Acurex Corp., Research Triangle Park, NC

Prepared for

Environmental Protection Agency
Research Triangle Park, NC

1987



U.S. Department of Commerce
National Technical Information Service
NTIS

PB88-104153

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA/600/J-87/071		

4. TITLE AND SUBTITLE	5. REPORT DATE
Screening Methods for the Identification of Organic Emissions from Indoor Air Pollution Sources (Journal Version)	1987
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
R. Merrill and R. Steiber (EPA/AEERL); and R. Martz and L. Nelms (Acurex)	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Acurex Corporation P.O. Box 13109 Research Triangle Park, North Carolina 27709	11. CONTRACT/GRANT NO. 68-02-3988
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
EPA, Office of Research and Development Air and Energy Engineering Research Laboratory Research Triangle Park, NC 27711	Journal Article; 10/85 - 7/86 14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES AEERL project officer is Raymond G. Merrill, Mail Drop 62B, 919/541-2558. In Atmospheric Environment, 21:2, pp. 331-336 (2/87).

16. ABSTRACT The paper discusses screening methods for identifying organic emissions from indoor air pollution sources. The development of on-line gas chromatographic (GC) screening procedures is necessary to permit subsequent evaluation of materials in test chamber studies. This screening uses techniques such as static vapor-phase sampling by headspace methods, and a dynamic method similar to the purge-and-trap procedures used for determining volatile organic compounds in water samples. These are methods of sampling that simulate chamber conditions on a small scale, while allowing emissions to be collected and analyzed. The evaluation is done to select GC columns and develop operating conditions that will permit the rapid and reliable separation of chemical compounds generated during testing. The GC procedure is used in the qualitative identification of chemical compounds by GC/mass spectrometry (MS). After identification of the compounds or their chemical classes, representative members are selected as calibration standards for the actual emission testing program. The standards selected are adequate to allow, in most cases, either quantitative or semi-quantitative calculation of the amount of each material present in the chamber exhaust gas. The use of response curves for the chemical classes allows subsequent recalculation of the amounts for each compound.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution Emission Organic Compounds Volatility Atmosphere Contamination Control Gas Chromatography Mass Spectroscopy Test Chambers	Pollution Control Stationary Sources Indoor Air Headspace Analysis	13B 07D 14G 14B 07C 20M 06K

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release to Public	Unclassified	8
	20. SECURITY CLASS (This page)	22. PRICE
	Unclassified	

EPA Form 2220-1 (9-73)

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA 22161

EPA/600/J-87/071
JOURNAL ARTICLE

Atmospheric Environment Vol. 21, No. 2, pp. 331–336, 1987.
Printed in Great Britain.

0004–6981/87 +0.00
Pergamon Journals Ltd.

NTIS is authorized to reproduce and sell this report. Permission for further reproduction must be obtained from the copyright owner.

SCREENING METHODS FOR THE IDENTIFICATION OF ORGANIC EMISSIONS FROM INDOOR AIR POLLUTION SOURCES

RAYMOND G. MERRILL and RAYMOND S. STEIBER
U.S. Environmental Protection Agency, Air and Energy Engineering Research Laboratory, Research Triangle Park, NC 27711, U.S.A.

and

ROBERT F. MARTZ and LEONARD H. NELMS
Acurex Corporation, Energy and Environmental Division, P. O. Box 13109, Research Triangle Park, NC 27709, U.S.A.

(*First received* 24 *October* 1985, *in final form* 28 *January* 1986 *and received for publication* 30 *July* 1986)

Abstract—Development of on-line gas chromatographic screening procedures is necessary to permit subsequent evaluation of materials in test chamber studies. This screening uses techniques such as static vapor-phase sampling by 'headspace' methods, and a dynamic method similar to the 'purge-and-trap' procedures used for determination of volatile organic compounds in water samples. These are methods of sampling that simulate the chamber conditions on a small scale, while allowing emissions to be collected and analyzed. The evaluation is done to select gas chromatographic columns and develop operating conditions that will permit the rapid and reliable separation of chemical compounds generated during testing. The chromatographic procedure is used in the qualitative identification of chemical compounds by gas chromatography/mass spectrometry. After identification of the compounds or, alternatively, their chemical classes, representative members are selected as calibration standards for the actual emission testing program. The standards selected are adequate to allow, in most cases, either quantitative or semi-quantitative calculation of the amount of each material present in the chamber exhaust gas. The use of response curves for the chemical classes allows subsequent recalculation of the amounts for each compound.

Key word index: Indoor materials, volatile organics, gas chromatography/mass spectrometry, headspace analysis, emission chamber testing.

INTRODUCTION

The procedures and results reported here are part of an ongoing program within EPA to develop ways to identify and mitigate potentially hazardous sources of indoor air pollution. Initial screening and identification of compounds or compound classes present in the gaseous emissions of materials used for construction will characterize potentially hazardous compounds. On-line methods are being developed to be used for emission chamber testing to assess the rate of compound emissions.

The screening techniques include static vapor-phase sampling by 'headspace' removal and dynamic methods similar to the 'purge-and-trap' procedures used for determination of volatile organic compounds in water samples. The screening methods allowed emissions to be collected from the headspace above a sample and concentrated before final analysis. Each headspace sampling technique was followed by concentration on Tenax–GC and gas chromatography/mass spectrometry (GC/MS). These methods simulate the vapor phase evolution of volatile organic material expected under conditions approaching those in engineering chamber studies reported by Sanchez *et al.* (1987).

Different sampling and analytical approaches are necessary for organic component screening of test materials. The techniques applied depend on such factors as polarity, solubility and boiling point (Schuetzle, 1980; Schlitte *et al.*, 1980). Schlitte and others have shown that different physiochemical characteristics of the wide range of pollutants found in ambient air dictate different sampling, enrichment and analysis procedures. Schuetzle (1980) has reviewed many of the applications of gas chromatography and mass spectrometry to both indoor and ambient organic analysis. According to Schuetzle, water in air samples is a major problem when sampling and analyzing gaseous pollutants. No one technique can eliminate water and related problems and address all organic compounds of interest. Molhave (1982) limited his organic screening of indoor construction materials to nonpolar or slightly polar compounds boiling between 25 and 250°C due to the diverse nature of the test materials. In fact, he reports no organic compounds with boiling points less than 56°C. De Bortoli *et al.* (1985) limited their GC/MS analysis of

volatile organic indoor pollutants to thermally stable compounds with boiling points of approximately 70°C (*n*-hexane). They also reported difficulty in detection and quantitative analysis of very polar or particularly basic compounds.

Sorbents such as charcoal (Molhave, 1982; De Bortoli *et al.*, 1985), carbon molecular sieves (Schlitte *et al.*, 1980) and Tenax–GC (Bursey *et al.*, 1978; Hansen, 1984) have been used to sample a range of volatile and semi-volatile compounds found in stationary source, ambient and indoor air samples. Extraction of organic material either directly from the source material or from a collection media such as XAD-2 is a common approach for sampling and recovery of semi-volatile and non-volatile organic compounds (Adams *et al.*, 1977; Lentzen *et al.*, 1978).

Various types of packed GC columns and capillary columns have been used for separation prior to identification and quantitation (Schlitte *et al.*, 1980; Lentzen *et al.*, 1978; Novotney, 1982). Gas chromatography has been the chief technique for separation of organic compounds with boiling points less than approximately 400°C. Air emission samples have been analyzed using flame ionization, electron capture and mass spectrometry (Molhave, 1982; Bursey *et al.*, 1978; Schlitte *et al.*, 1980; Novotney, 1982; De Bortoli *et al.*, 1985).

This approach represents one in a series devoted to qualitative identification of organic compounds originating from indoor construction materials using gas chromatography/mass spectrometry. Quantitative analysis of compounds and their emission rates under various environmental conditions are reported by Sanchez *et al.* (1987). The approach used for materials screened and reported in this paper is similar in concept to the approaches used by these other groups investigating general air pollution and the effects of construction materials on indoor air quality. The complete method is summarized, and the results from the applicable parts of the approach of the analysis of compounds collected on Tenax–GC from indoor construction materials are given.

EXPERIMENTAL

A Hewlett Packard model 5993 GC/MS-equipped with a 21MX computer system was used for all analyses in this study. The GC/MS was equipped with a heated, on-column injection port, and modified to accept a gas-phase sample from a Hewlett Packard model 7675A Purge and Trap instrument. Two packed columns were used for these studies: a 2 m × 0.2 mm id SP-2400 on Supelcoport, and a 2 m × 0.2 mm id 1% Carbowax on Carbopack B. The GC/MS was run under the nominal conditions given in Table 1.

Table 1. GC/MS conditions for Phase I screening analysis

Initial temperature	45–55°C
Time at initial temperature	2–3 min
Oven ramp rate	10°C min^{-1}
Final temperature	180–250°C
Time at final temperature	40–50 min
Mass range for scan	35–350 mz^{-1}

GC/MS screening

During the course of the evaluation, the chemical compounds that are found in the headspace of the material are used to select a gas chromatographic (GC) column and to develop a set of operating conditions that will permit the rapid and reliable separation of these materials during chamber testing. The compounds found in the sources can be divided into groups which can be analyzed by a selected technique (windows of analysis applicability). The three windows cover three boiling point ranges.

Window 1 includes compounds which have boiling points between −160 and 30°C. This window is bounded at the low end by the hydrocarbon methane and at the upper end by the hydrocarbon propane. Sampling for compounds in this window can be performed by collecting whole-gas samples in ambient pressure bags/bulbs or by compressing the gases in a passivated metal sampling sphere. Part of the window, down to −14°C, can also be sampled with charcoal as the adsorbent.

Window 2 covers materials in the boiling point range from 30 to 125°C. These are compounds which are efficiently collected and recovered from Tenax–GC (Adams *et al.*, 1977; Hansen, 1984). Window 3 covers materials in the boiling point range greater than 125°C. Compounds in this window are sampled using filter media and extractable sorbents such as XAD-2. Samples are generally recovered by extraction, and analyses are performed by liquid injection of a portion of the sample into the GC (Longbottom and Lichtenburg, 1982; Harris *et al.*, 1984).

The data reported are for compounds from Window 2. The approaches used to identify compounds and compound classes in this window are described in detail.

Phase I: screening. During Phase I, GC chromatograms from headspace analysis and from chamber sampling are compared. The separation of components is optimized, and the peak patterns from the headspace and chamber sample analysis are matched. The chromatographic procedure is also used for qualitative identification of the compounds by gas chromatography/mass spectrometry (GC/MS) in Phase II.

Phase II: qualitative identification. The GC/MS analysis provides information for the initial identification of emission materials. The total mass scan for each of the major peaks in the reconstructed ion chromatogram is interpreted with the aid of computer searching, comparison to the Aldermaster 8 peak index, comparison to the mass spectra of known compounds available in the EPA/NIH library of mass spectra, and/or application of 'first principles' for interpretation of mass spectral fragment patterns (McLafferty, 1973).

Phase III: quantitation. The identifications made in Phase II are confirmed by pure compound spiking. In this phase both the retention time and the mass spectra of known spiked compounds and unknown peaks are compared for positive identifications.

Choice of calibration method

After identification of the compounds or their chemical classes, representative members of the group were selected for use as calibration standards for the on-line chromatographic analysis used during the actual testing program. The quantification methods used in the indoor air program are based on the works of Andeatch and Feinland (1960), Perkins *et al.* (1972) and Clementi *et al.* (1972). These and other investigators have examined the response of the FID detector and found that it is based on 'effective carbon number.' This phenomenon is an outgrowth of the investigation of several groups into the theoretical mechanisms responsible for factors contributing to FID response.

Theory suggests that the absolute response of the FID to a given compound is directly related to its effective carbon number. For hydrocarbons (compounds containing carbon and hydrogen only), the response is determined by the number of carbon atoms present to within a relatively small margin of error. Thus, the FID response of a mole fraction of butane will be approximately four times that of methane. Then, when the relative molecular weights are factored into the response, the detector provides a linear response to the weight of carbon present in the molecule, for all species. This relationship is shown graphically in Fig. 1.

However, for molecules containing other atomic species, such as oxygen, chlorine and nitrogen, the heteroatom in each case causes a reduction in the ionization current, and thus a lowering of FID response. In some of these cases, the actual form of the heteroatom determines the effect on the response. An oxygen atom present as an alcohol, for example, reduces the response by only a small amount for most species, while the presence of a carbonyl moiety has the effect of completely offsetting the presence (or response) of one carbon atom. Thus, the FID is found to be insensitive to both formaldehyde and formic acid. In like manner the actual molecular response to acetone (C_3H_6O) is about the same as that of ethane, (C_2H_6). The overall effects of different moieties on magnitudes of FID response are summarized in Table 2. Thus, a carbonyl moiety gives a (−1) effect, completely offsetting the carbon atom of the carbonyl.

Since heteroatom substitution has a consistent and predictable effect on FID response, it follows that (when the FID response for a class of compounds is plotted vs the weight of material injected onto the GC column) a family of linear response curves with varying slopes can be obtained for the various chemical classes of interest. These response curves can be used to calculate the quantities of the unknown compounds if the compound class of the unknown compound is known.

It is not always possible to identify every compound in a complex mixture from an emissions source. However, with the use of advanced identification techniques such as gas chromatography/mass spectrometry, the compound class of unknown compounds can usually be established, and 'generic' response factors for those compound classes can be determined using the methods described above. Application of the response factors for the compound class allows calculation of the amount of material present, on a weight basis, with a reasonable degree of accuracy.

Table 2. Major components identified during Phase I screening of floor adhesive

Compound or class	mz^{-1}
Dimethyl ether	46
2-Propanol	60
Cyclopentadiene	66
Methyl ethyl ketone	72
Methylcyclopentadiene	80
Methylpentanone	98
C-7 Alkanes	98
Methylcyclohexane	98
C-8 Alkene isomers	112
Dimethyl hexene isomers	112
Dimethyl cyclohexane or trimethyl pentene isomers	112
C-8 Alkane isomers	114
C-7 Ketones or aldehydes	114
C-9 Alkene isomers	128
Dimethyl benzenes (xylenes)*	106
C-9 Alkane isomers	128

* Possible Tenax artifact.

For materials that have been screened for chamber emissions studies in our laboratories, such as the floor adhesive, a large number of compounds have been detected. However, the number of chemical classes identified from a single source material is quite small, making the application of the class calibration technique described here attractive from both a time and resource standpoint.

The compound class standards selected by this method are adequate to allow, in most cases, either quantitative or semi-quantitative calculation of the amount of each material present in the chamber exhaust gas. The use of response curves for the chemical classes allows subsequent recalculation of precise amounts for each compound in chamber emission samples (Sanchez *et al.*, 1987).

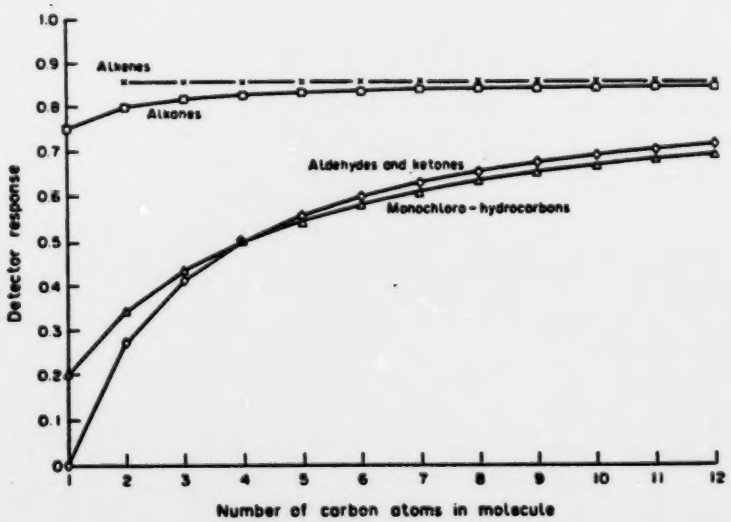


Fig. 1. FID response for four compound classes.

TYPICAL RESULTS

Floor adhesive results

For high emission compounds in adhesives, the quantity of volatile organic material in the sealed headspace over a 0.1–0.25 g sample was more than enough to meet the detection limit requirements of the GC/MS system. The analyses were done to detect the major components coming from the adhesive after it was first applied. Samples were placed in individual glass bottles sealed with Teflon-faced septa. The first screening of this material involved warming the sample at approximately 70°C for several hours. A second set of analyses was performed on a fresh sample equilibrated at room temperature. A gastight syringe was inserted through the septum and approximately 0.25 ml of the headspace gas was withdrawn. This gas sample was injected through a heated port onto one of several 0.2 mm id, 2 m packed GC columns. The headspace gas was separated into its components, and the mass spectra of these components were used to identify the compound or compound class.

Pure compounds were used to spike test materials to confirm the initial identification for each of several components found in the test material headspace. For high emission materials (e.g. floor adhesive) the analyses involved preparing a sealed headspace of the pure compound by introducing approximately 2 μl of liquid into a 10 ml septum-sealed vial. Equal volumes of the pure compound headspace and the floor adhesive headspace were mixed and injected directly onto the GC/MS column. An example of floor adhesive headspace is shown in Fig. 2.

Two types of information are generated from this approach to GC/MS analysis. First, components in the emission sample are matched by retention time with known materials. Second, the mass spectral pattern of the known and unknown material can be compared to ensure the correct identification of the unknown. Both types of data are necessary to confirm the identity of components in emission samples. This is significant for a material like the floor adhesive because the components found were isomeric variations of the same molecular weight. For example, heptane was evaluated as a possible component using the spiking technique. This component was not well resolved from the C-7 alkenes. The possibility of heptane as a major component in the test material headspace was ruled out by the difference of its spectrum from the mass spectra of compounds with approximately the same retention time. For high emission rate material (e.g. the floor adhesive) screening by direct injection of sample headspace onto the GC column provided adequate sensitivity for procedure development. GC/MS analysis indicated that the lowest molecular weight materials emitted from the floor adhesive were in the C6–C9 boiling point range (i.e. in Window 2). A typical reconstructed ion chromatogram of the floor adhesive headspace is shown in Fig. 2. The major components in this sample are identified in Table 2. From the screening list it becomes obvious that the floor adhesive is predominantly saturated and unsaturated hydrocarbons in the C-7 to C-8 range.

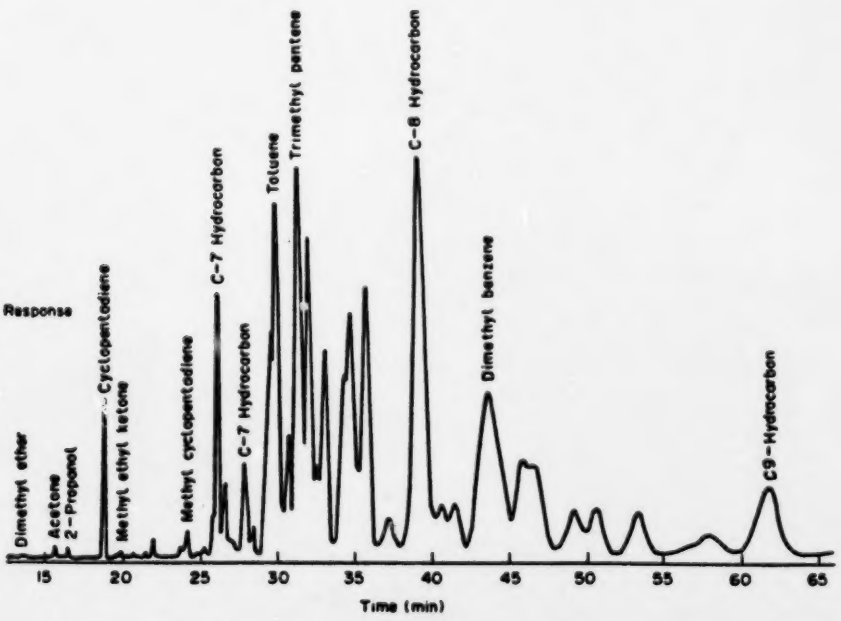


Fig. 2. Reconstructed ion chromatogram of floor adhesive volatiles.

Screening of the floor adhesive material for Window 3 compounds indicated materials in the headspace at much lower levels in the boiling point range of the C-9 to C-18 hydrocarbons.

Particle board results

For low emission rate materials (e.g. the particle board), a different approach was needed for screening and method development. The headspace over these materials contained too little material to test by direct injection. Therefore, a modification of the EPA priority pollutant purge-and-trap procedure was used. The purge-and-trap procedure calls for passing inert gas through an aqueous liquid to drive off volatile organic materials. The same procedure can be applied to solid samples if certain conditions are met. The material must be swept with purge gas slow enough to allow compounds to diffuse from the emitter to the gas phase. Sufficient material and passage of purge gas must be used to accumulate components to a level adequate for detection by GC/MS. These conditions were met for freshly cut particle board by using approximately 0.5–1.0 g of material cut and broken into approximately 2 mm × 2 mm × 5 mm pieces and passing approximately 70 ml of helium gas over the sample at a flow rate of 10 ml/min.

Analysis for confirmation of the low emission rate materials involved spiking approximately 100 ng of material in methanol onto fresh particle board chunks in the purge tube. Retention time and mass spectral data were again used to confirm the compounds identified in the original screening of the material.

Many compounds were identified in the headspace emissions of the particle board sample similar to the materials testing of Molhave (1982) and the ambient work of Schlitte *et al.* (1980). Table 3 lists the major components identified in the Phase II screening of the particle board.

Phase III confirmation was performed on six compounds as noted in Table 4. All six compounds were confirmed by retention time and by mass spectral comparison. Figure 3 shows a typical reconstructed ion chromatogram of the particle board headspace and the particle board headspace spiked with the six compounds of interest. In all cases the pure compounds were run separately and combined with the unknown headspace to ensure accuracy of identification.

Table 3. Window 2 compounds and compound classes found in particle board headspace

Compound or class	mz^{-1}
Acetonitrile	41
Dichloromethane*	84
Acetone	58
2-Propanol†	60
Methylacetate†	74
Butenal	72
Methyl ethyl ketone	72
Acetic acid†	60
Ketone or aldehyde	72
Methylpentane	86
Ketone or aldehyde; possibly methylbutanal	86
Pentene	70
Furfural	96
Hexanal	100
Toluene	92
Heptane	100
Pinene isomer†	136
Pinene isomer	136
Carene isomer†	136
Carene isomer	136
Octane	114
Benzaldehyde†	106
Dimethylhexadiene	110
Aliphatic nitrile	121

* Possible laboratory contaminant.
† Compounds confirmed in Phase III analysis.

Table 4. Multiplier for FID response for functional group corrections

Aliphatic carbon	1.0
Olefinic carbon	0.95
Acetylenic carbon	1.3
Carbonyl carbon	0.0
Nitryl carbon	0.13
Ethereal oxygen	−1.0

CONCLUSIONS

A multitude of potentially toxic substances can be present in emissions which impact indoor and outdoor air quality. Analysis of these compounds in 'real world samples' presents formidable analysis problems. Analysis of the individual materials used in indoor construction contains fewer compounds often of similar composition. Compounds emitted from these materials are still quite complex in kind and number. Screening for potentially toxic compounds in these materials dictates a logical thorough approach. First, materials to be tested must have their manufactured composition documented. This step is crucial to anticipate the compounds expected in their vapor-phase emissions. Second, effective analytical methods for identification and quantification of potentially hazardous components coming from these materials must be developed, and must be re-evaluated with each new material to be tested.

Identification of compounds in any of the windows must include three parts. First the material must be screened to determine both appropriate analytical conditions and 'window(s)' of compounds. Second, each window must be screened to tentatively identify the compounds or compound classes present in the headspace or emission sample. Finally, compounds of interest must be confirmed. Confirmation is accomplished by the addition of a known material to the complex mixture and analysis of the mixture of known and unknown headspace simultaneously by GC/MS.

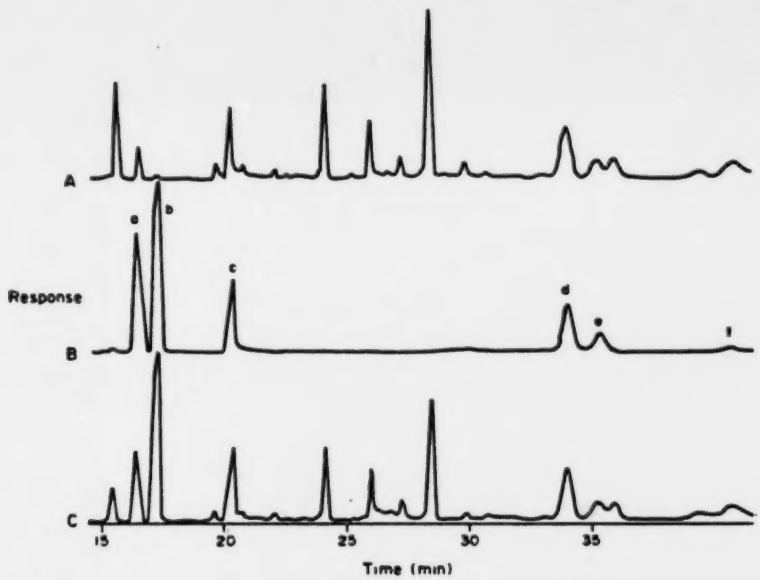


Fig. 3. Reconstructed ion chromatogram of particle board volatiles. Trace A—particle board volatiles alone. Trace B—pure compounds used for confirmation, a. 2-propanol, b. methyl acetate, c. acetic acid, d. carene isomer, e. pinene isomer, f. benzaldehyde. Trace C—particle board volatiles plus pure compound spike.

The procedures and data reported here and by Sanchez *et al.* (1987), Dunn (1987) and Blackard (1987) provide an initial approach for screening emissions from individual sources which impact total indoor air quality. The results obtained using the analytical procedures reported for multicomponent organic analysis address one part or 'window' of the range of compounds possibly present in any given material.

Disclaimer—Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

REFERENCES

Adams J., Menzies K. and Levins P. (1977) Selection and evaluation of sorbent resins for the collection of organic compounds. EPA-600/7-77-044 (NTIS PB 268559).

Andeatch J. A. and Feinland R. (1960) Continuous trace hydrocarbon analysis by flame ionization. *Analyt. Chem.* 32, 1021.

Blackard A. (1987) Automation of an emissions testing facility. *Atmospheric Environment* 21, 355–357.

Bursey J. T., Bunch J. E., Williams R. N., Berkley R. E. and Pellizari E. D. (1978) International Laboratory, Jan–Feb., p. 11.

Clementi S., Savelli G. and Verfoai M. (1972) Relative molar response of flame ionization detector to some heteroaromatic compounds. *Chromatographia* 5, p. 413.

De Bortoli M., Knoeppel H., Pecchio E., Peil A., Rogora L., Schauenburg H., Schlitt H. and Vissers H. (1985) Integrating real life measurements of organic pollution in indoor and outdoor air of homes in northern Italy. Commission of the European Communities, Luxembourg

Dunn J. E. (1987) Models and statistical methods for gaseous emission testing of finite sources in well-mixed chambers. *Atmospheric Environment* 21, 425–430.

Hansen E. (1984) Protocol for the collection and analysis of volatile POHCs Using VOST. EPA-600/8-84-007 (NTIS PB 84-170042).

Harris J., Larsen D., Rechsteiner C. and Thrun K. (1984) Sampling and analysis methods for hazardous waste combustion. EPA-600/8-84-002 (NTIS PB84-155845).

Lentzen D. E., Wagoner D. E., Estes E. D. and Gutknecht W. F. (1978) IERL-RTP procedures manual: level 1 environmental assessment (Second Edition). EPA-600/7-78-201 (NTIS PB 293795).

Longbottom J. and Lichtenburg J. (eds) (1982) Methods for organic chemical analysis of municipal and industrial waste water; test methods. EPA-600/4-82-057 (NTIS PB 83-201798/LA).

McLafferty F. W. (1973) *Interpretation of Mass Spectra*, 2nd Edn. Benjamin/Cummings Publishing, Reading, MA.

Molhave L. (1982) Indoor air pollution due to organic gases and vapours of solvents in building materials. *Envir. Int.* 8, 117–127.

Novotney M. (1982) Comprehensiveness and separation of samples (during assessment of potential health hazards). *Assess: Multichem. Contam, Proceedings International Workshop.*

Perkins G. Jr., Laramy R. E. and Levely L. D. (1972) Flame response in quantitative determination of high molecular weight paraffins and alcohols by gas chromatography. *Analyt. Chem.* 35, 360.

Sanchez D. C., Mason M. and Norris C. (1987) Methods and results of characterization of organic emissions from an indoor material. *Atmospheric Environment* 21, 337–345.

Schlitte H., Knoepe H., Versino B., Peil A., Schauenburg H. and Vissers H. (1980) Organics in air: sampling and identification In *Sampling and Analysis of Toxic Organic in the Atmosphere*, pp. 22–35. ASTM STP 721, American Society for Testing and Materials.

Schuetzle D. (1980) Air pollutants (and mass spectrometry). In *Biochemical Applications of Mass Spectrometry*, first supplementary volume. Wiley, New York.

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This article documents research that was conducted under the auspices of the U.S. Environmental Protection Agency (USEPA). As an arm of the government, the USEPA has a paid up, non-exclusive, irrevocable, worldwide license to reproduce, prepare derivative works, and distribute to the public all of the material contained herein, and to grant others acting on its behalf the right to do so. The USEPA grants to the National Technical Information Service, Department of Commerce, the right to act as its agent in the distribution of this material.